Pacific Southwest Forest and Range
Experiment Station Keith Arnold, Director
Forest Service - U.S. Department of Agriculture

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# PRESCRIBED BURN FIRECLIMATE SURVEY 2-57

FIRE
ENVIRONMENT
STUDIES

C.M. Countryman

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Errata

Page 8, line 3, change "west and northwest" to "west and southwest."

Page 13, Figure 11 caption, change "Station 2" to "Station 3."

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U. S. Weather Bureau

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U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION

## FOREWORD

### Fireclimate Studies--Their Purpose

Experience and research have taught firefighters a good deal about wildland fire. Its general relationship to weather, fuels, and topography are well known. Application of this knowledge to control of fire is frequently hampered by lack of information about the behavior of fireclimate in specific places--how wind, temperature, humidity, and fuel moisture are affected by topography, water bodies, season, and the fire itself. The existing system of weather stations provides enough information for general weather forecasts but not enough to define local fireclimate patterns. The stations are relatively few, widely spaced, and seldom equipped with recording instruments. They gather only momentary samples of weather conditions and provide no information on the way fire itself affects the patterns.

To obtain this needed information, the Station has started studies aimed at establishing some of the principles controlling local fireclimate patterns and the effect of fire on these patterns. A four-pronged attack will be made on the problem:

1. Semi-permanent fireclimate surveys wherein distinct topographic types will be intensively instrumented for one or more years primarily for the study of variations in local fireclimate patterns in relation to more general weather patterns.

2. Temporary or mobile surveys that will permit exploratory studies of fireclimate patterns around prescribed burns and wildfires and short-term detailed studies of various phases of broader scale fireclimate patterns.

3. Analysis of existing fire and weather records to establish, if possible, the relation of pattern of past fires to weather patterns.

4. Controlled laboratory studies aimed at determination of the fundamental laws governing fireclimate patterns and effects of fire on these patterns.

## ABSTRACT

Prescribed Burn 2-57 was the second of four prescribed burns studied in 1957. In this burn we were particularly interested in studying air flow on the lee side of a ridge oriented approximately at right angles to the prevailing wind. Experience has shown that erratic fire behavior frequently occurs under this situation. Instrumentation and observation methods were such that we could also further explore the techniques for determining local fireclimate patterns and relating these patterns to general weather.

Fire behavior followed very closely the wind pattern indicated by the survey. A firewhirl developed in an area where vertical eddy circulation was found, and the fire crossed the fireline at a point where the survey indicated persistent cross-line winds.

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## THE SURVEY AREA

This prescribed burn was made on the Adams Ranch property in the lower foothills of the west slope of the Sierra Nevada, about 15 miles southwest of Sonora, California. Nearly all of the 1,000-acre burn area was on the east-facing slopes on the west side of Don Pedro reservoir. Side slopes of the main canyons leading into the reservoir and the slopes above the reservoir itself were steep. The south and southwest parts of the burn area were in more gently rolling country. Elevations within the burn boundaries ranged from 600 to 1,200 feet.

Ground cover varied greatly. The area south and west of South Ridge (fig. 1) was chiefly open grass-woodland. The cover in the bottom of Survey Canyon above the 750 foot contour line was also of this type. The steep slopes above the reservoir were covered with dense brush, the heaviest stand of brush being on the northeast side of South Ridge (fig. 2). Here the brush, mostly chamise, manzanita, and scrub oak, grew 6 to 8 feet tall and was interspersed with many digger pines. No fuel preparation was done before the burn.

## SURVEY PROCEDURE

To use available equipment most efficiently, we decided to concentrate efforts in the northeast corner of the burn, particularly in Survey Canyon. This area was chosen because the topography was better defined than in other parts of the burn and because the heavy fuel concentrations in this area could be expected to produce the greatest fire activity.

Five sites were selected for wind speed and direction recording instruments. Station 1 (fig. 1), on the point of a spur ridge about 150 feet above the reservoir, was chosen because of the great variability of wind flow noted here during presurvey reconnaissance. Station 3 was placed at the edge of a small, flat bench on the slope of the same spur ridge on which Station 1 was located. This station was also in a small canyon leading into the reservoir and was intended to measure air movement in this canyon and to trace air flow toward Station 1.

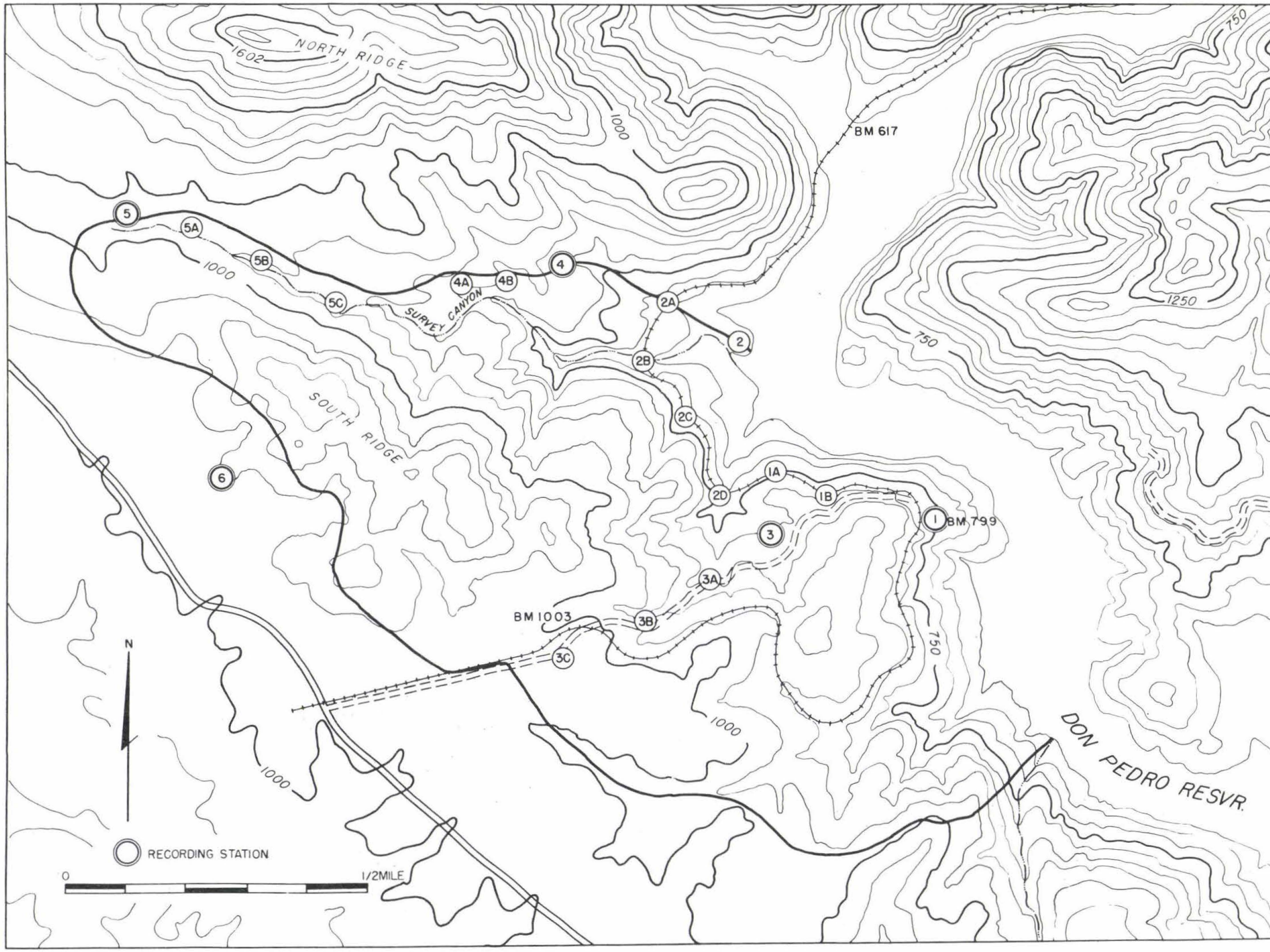


Figure 1.--Prescribed Burn 2-57, August 10, 1957.

Station 4 was on a small flat area just above the point where Survey Canyon dropped off more steeply into the reservoir. The canyon bottom in this area was covered with oak trees 30 to 50 feet tall but open and park-like underneath. The anemometer and wind vane were placed about 6 feet above the ground in the open area under the tree crowns so as to measure the air flow under the crown canopy.

Station 5 was near the head of Survey Canyon. The canyon bottom was fairly open at this point, with only scattered oak trees. This station was set up to record speed and direction of the wind in the upper reaches of the canyon.

Station 6, in the open rolling country outside of the burn area, served as a reference station, free of fire influence, and measured the general wind direction and speed.

Besides the five recording stations, we selected 15 other sites where measurements with non-recording portable instruments were made at irregular intervals. These sites were selected so as to supplement the recorded data in determining wind flow patterns.

Hygrothermographs were set up at Stations 1, 3, and 5 to provide continuous records of temperature and humidity. Psychrometric readings were taken manually at frequent intervals at the other stations.

Observations were started on August 2 and continued through August 10 when the area was burned.

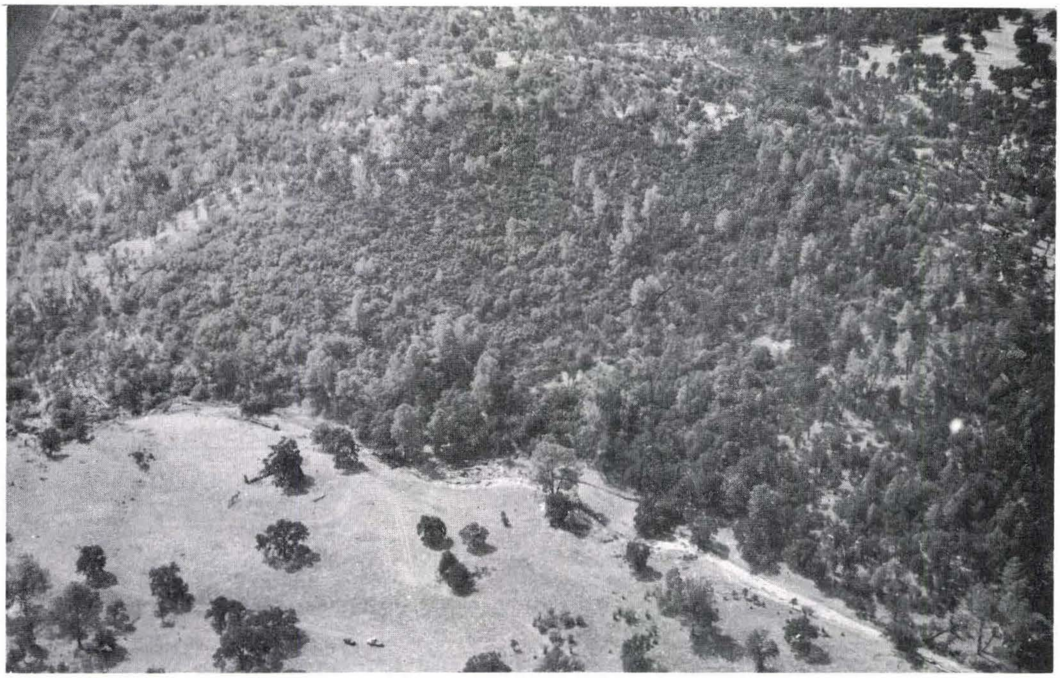

Figure 2.--Fuel conditions along south ridge.

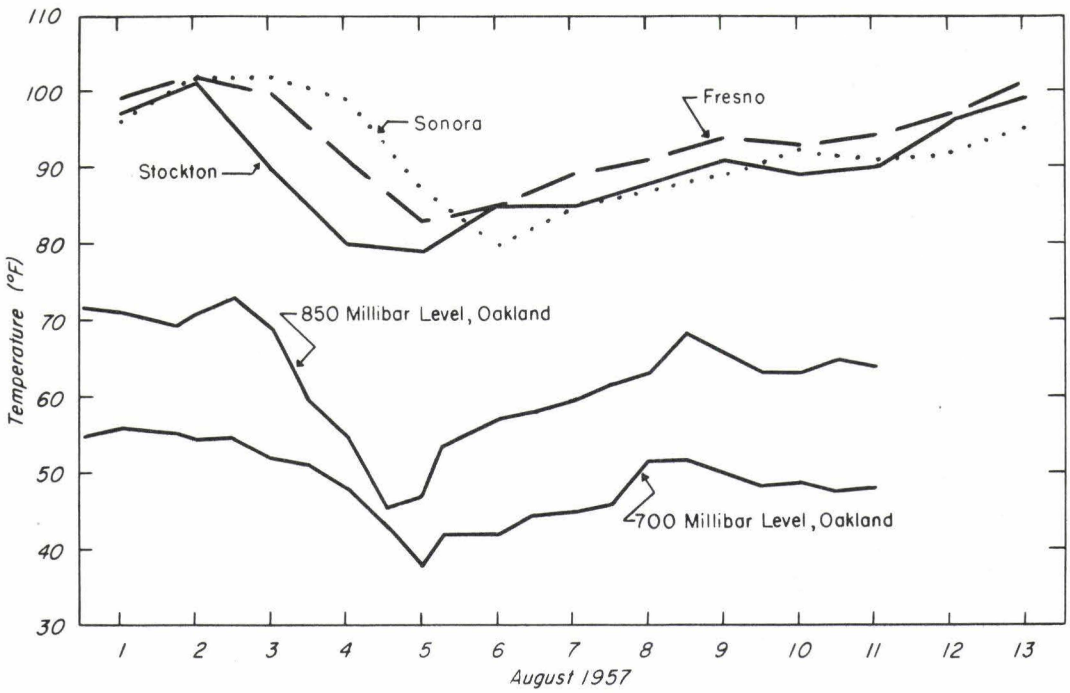


Figure 3.--Maximum temperatures for selected stations: 850 and 700 millibar temperatures for Oakland.

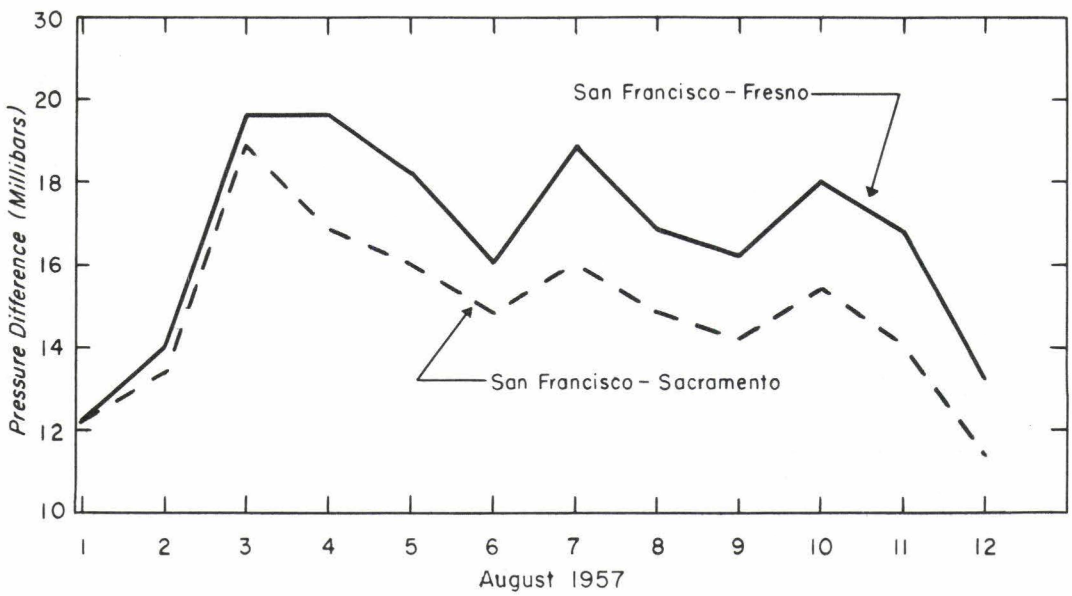


Figure 4.--Pressure differences, San Francisco-Sacramento and San Francisco-Fresno, August 1 to 12, 1957.

## GENERAL WEATHER

Most of the survey was conducted during a period of below-normal temperatures. The weather was hot the first three days of the survey, August 1, 2, and 3. But marked cooling was observed in the lower Sacramento and San Joaquin valleys August 3 and in the survey area August 4. This cooling was associated with the remnants of a cold front which moved through the area. Cooling occurred not only at the surface, but aloft as well. From August 3 to 5 temperatures over Oakland dropped 16° F. at 700 millibars (about 10,000 feet) and more than 26° F. at 850 millibars (about 5,000 feet). Figure 3 shows the cooling that took place at the surface at several stations in the area, and at the 850 and 700 millibar levels over Oakland. It also shows that during the rest of the period of the survey the general trend of temperature was upward. Surface temperatures were still below normal on the day of the burn, but the upward trend continued after the burn and temperatures were above normal again by August 12.

The thermal trough in the sea-level pressure pattern, which is usually present in the central valley of California during the summertime, was observed at the beginning of the period and on through August 3. By August 4 higher sea level pressures moved into northern and central California behind the remnants of the cold front and filled the thermal trough. The pressures in the interior did not rise as much as did the pressures along the coast. This resulted in an increase in the pressure gradient from the coast inland and aided the advection of cooler maritime Pacific air into the central valley and the western slopes of the Sierra Nevada. Pressure differences between San Francisco and Sacramento, and between San Francisco and Fresno (fig. 4) were high from August 3 through 11 and then began to decrease. The trend corresponds to the temperature changes observed at valley and foothill stations. Afternoon relative humidities also corresponded to this pattern. They were generally less than 15 percent through August 3, in the 20's from August 4 through 10, and then dropped below 20 percent again.

Judging from the upper-air measurements at Oakland and the surface temperatures near the survey area, the thermal structure of the air during the afternoons resulted in a relatively unstable layer from the surface to about 5,000 feet mean sea level on most days, including the day of the burn. Above this level the air was relatively stable. During the time of maximum cooling aloft, on August 4 and 5, the unstable layer was probably 1,000 to 2,000 feet deeper.

# RESULTS

## Local Fireclimate Patterns

While the survey was in progress, our data showed that we were concerned with two wind circulations in this area. The first of these was the general wind flow brought about by pressure patterns and modified by large-scale thermal effects in this section of the Sierra Nevada. This flow was generally from a westerly direction and was most apparent on the west-facing slopes and higher ridges.

The second circulation was the flow pattern set up by the thermal effects of local heating and cooling. Because these local circulation patterns can be overridden or modified by the general wind flow, they were most evident at times and places where the effect of the general circulation was least. This usually occurred during early forenoon hours and in topographic situations that were protected from the general wind flow.

From recorded data and supplemental observations, we were able to prepare maps of the survey area showing the local and general air flow patterns to be expected at different times during the day. It must be emphasized that these flow patterns were those found for the synoptic weather conditions that prevailed during the survey. Other synoptic conditions could well lead to other patterns.

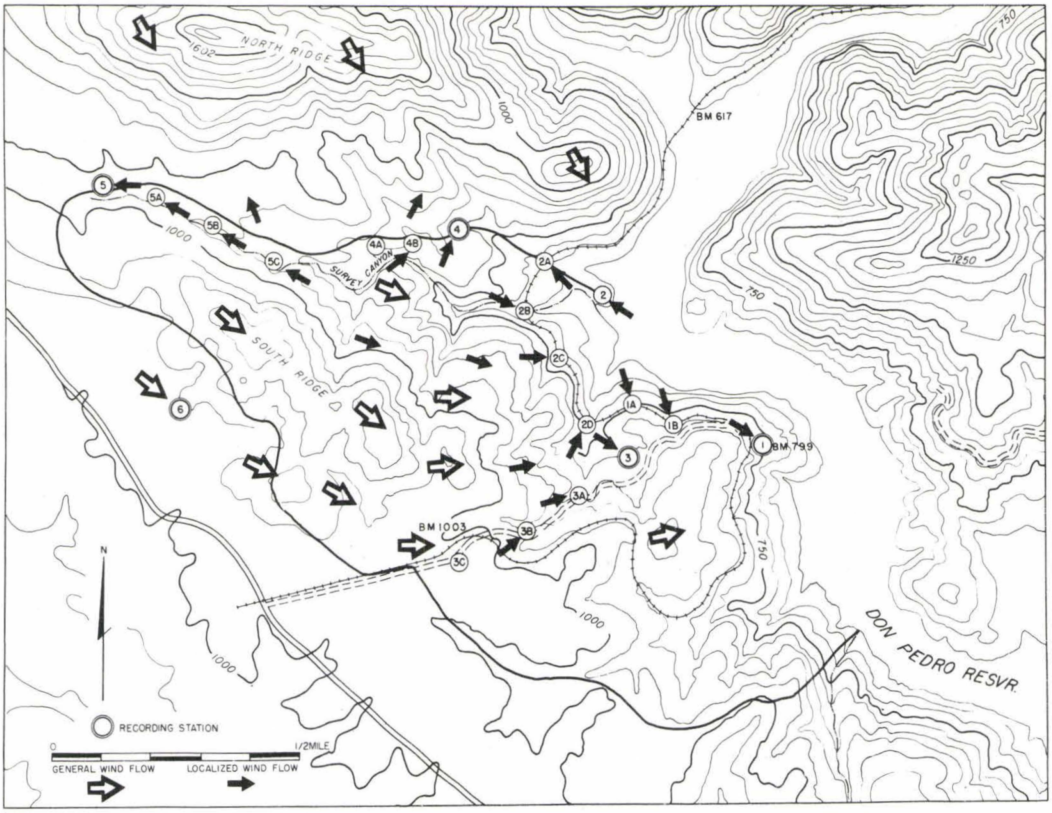


Figure 5.--Wind pattern, Prescribed Burn 2-57 for 0800 hours.

<u>Conditions at 0800</u>.--During the early morning hours before sunrise the general windflow was from the northwest at 1-5 m.p.h. with light down-canyon and down-slope winds in the survey area on the east-facing slopes. Shortly after sunrise, when these slopes were beginning to be warmed by the sun, up-canyon and up-slope winds began. Wind direction on the ridges and west slopes continued from the northwest. The map for 0800 hours (fig. 5) is typical of the wind flow pattern for the early forenoon hours.

Of particular interest is the southwest wind at Station 4. At this time the wind direction here was probably influenced by strong heating of the southeast slopes of North Ridge where the vegetation was sparse and the soil dark in color. Note also the erratic wind directions and tendency toward eddy circulation to the north and west of Station 3.

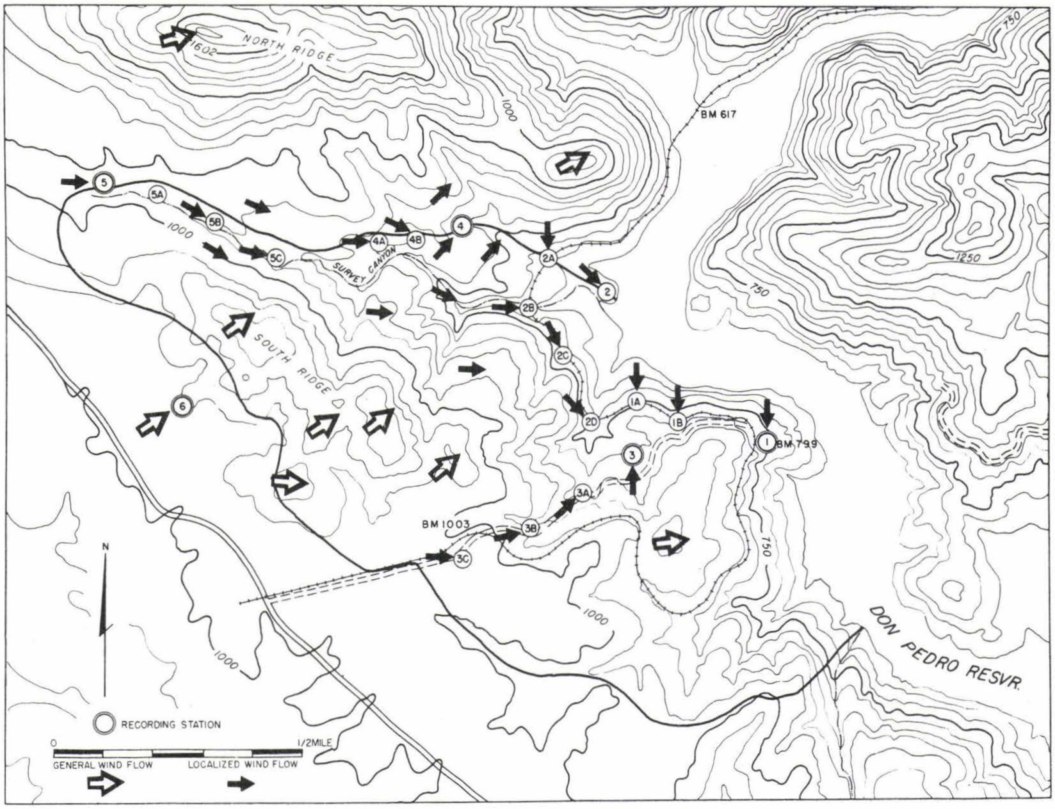


Figure 6.--Wind pattern, Prescribed Burn 2-57 for 1000 hours.

Conditions at 1000.--As the day progressed, the west slopes of the Sierra and in the survey area received more heat. As a result the general wind flow shifted to the west and northwest and became stronger. Bt 1000 hours the general wind flow predominated (fig. 6). Down-canyon and down-slope winds prevailed on the east facing slopes except in the areas topographically sheltered from the westerly winds such as the steep slope just above the reservoir.

Winds on the ridges and west slopes (as at Station 6) were fairly constant in direction and speed. In east-facing canyons the wind, though predominately from the west, was very erratic in direction and gusty with frequent calm periods. Most erratic wind behavior was observed at the lower end of Survey Canyon and in the area around Station 1.

This same general pattern of wind flow persisted through the forenoon and early afternoon.

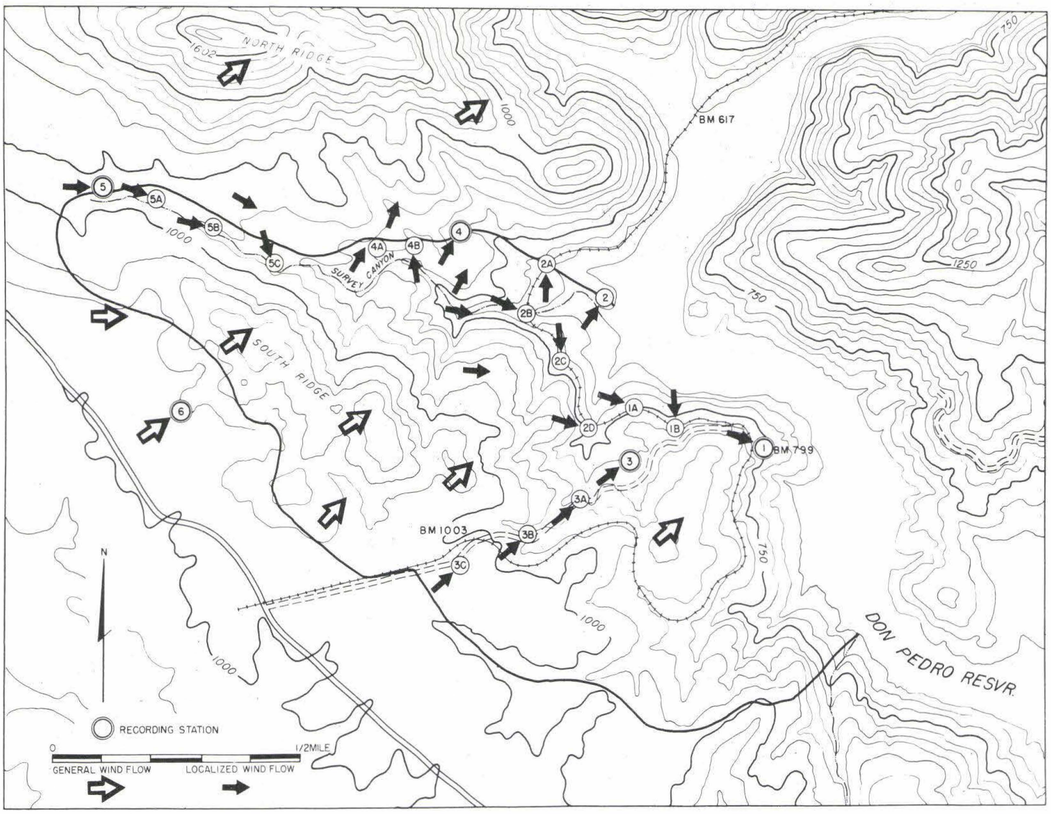


Figure 7.--Wind pattern, Prescribed Burn 2-57 for 1400 hours.

Conditions at 1400.--At 1400 the wind pattern (fig. 7) for the most part was similar to that for 1000 hours: a general flow from the west and down-canyon and down-slope over most of the survey area. The tendency for eddy circulation in the vicinity of Station 3 was still present. In Survey Canyon, heating of the south-facing slopes of North Ridge was beginning to affect the local circulation. Air flow around Stations 4, 4A, and 4B now had a definite trend cross canyon toward North Ridge. Stations 2 and 2A also showed a tendency toward up-canyon flow in the reservoir basin.

Wind speeds in the vicinity of Station 6 were from 6 to 10 m.p.h. and 3 to 6 m.p.h. in Survey Canyon.

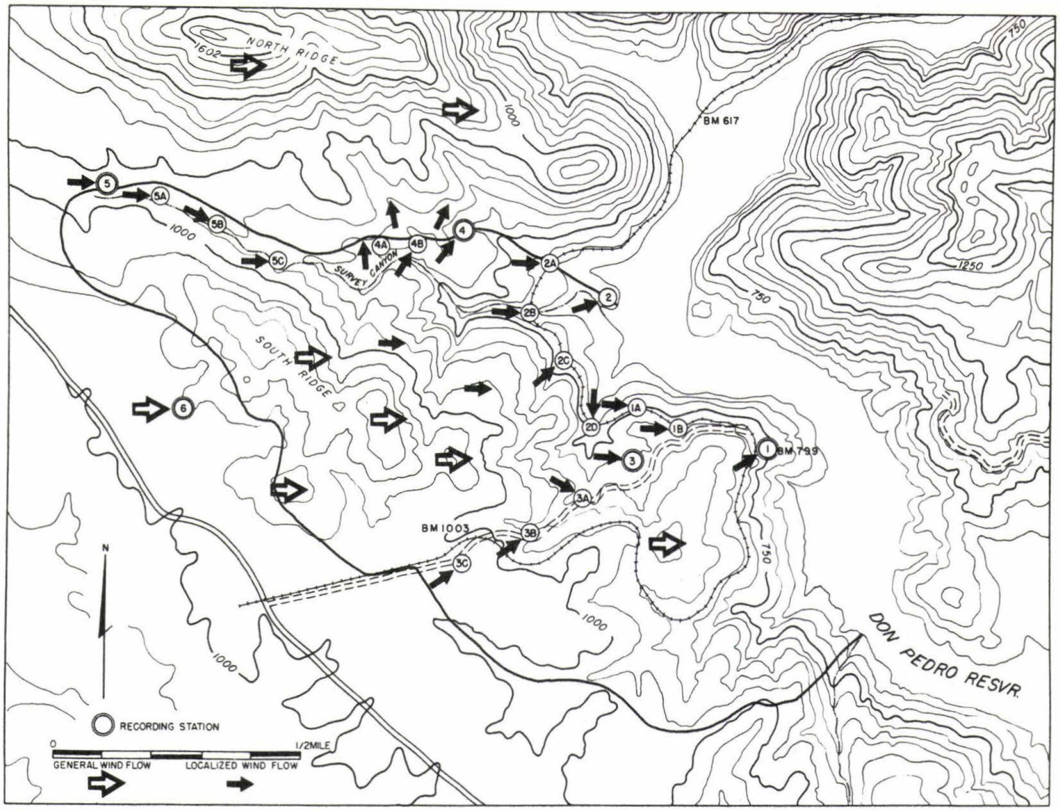


Figure 8.--Wind pattern, Prescribed Burn 2-57 for 1800 hours.

Conditions at 1800.--The air flow toward North Ridge in the Station 4 area continued throughout the afternoon. This flow was still present at 1800 hours (fig. 8) although the general wind flow had increased in speed and was showing evidence of dominating the entire wind pattern. The eddy circulation near Station 3 was less pronounced and the wind direction at Station 1 more steady and consistent with the general wind flow.

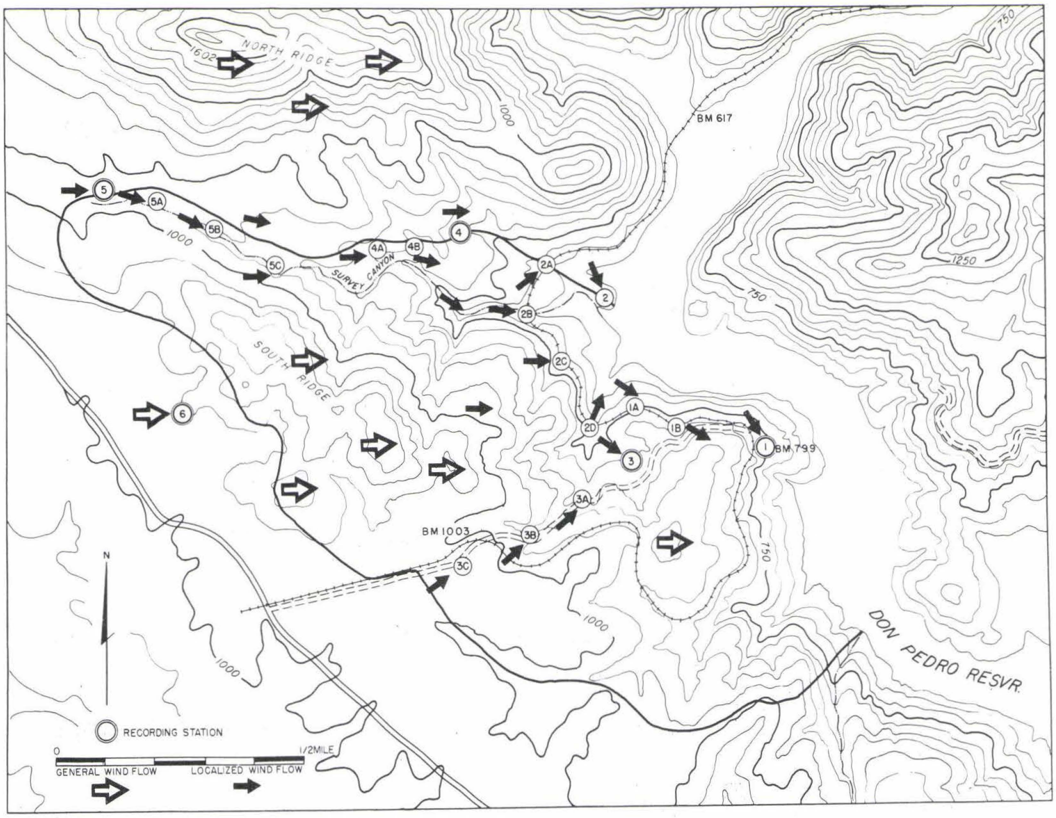


Figure 9.--Wind pattern, Prescribed Burn 2-57 for 2100 hours.

<u>Conditions at 2100</u>.--After sundown any tendency for upslope wind movement soon ceased, and the general wind flow dominated the wind pattern in the survey area. Typical nighttime winds (fig. 9) in Survey Canyon were generally light in the lower portion (1 to 3 m.p.h.). In more open areas in this canyon the wind speed was about the same as at Station 6 (3 to 6 m.p.h.).

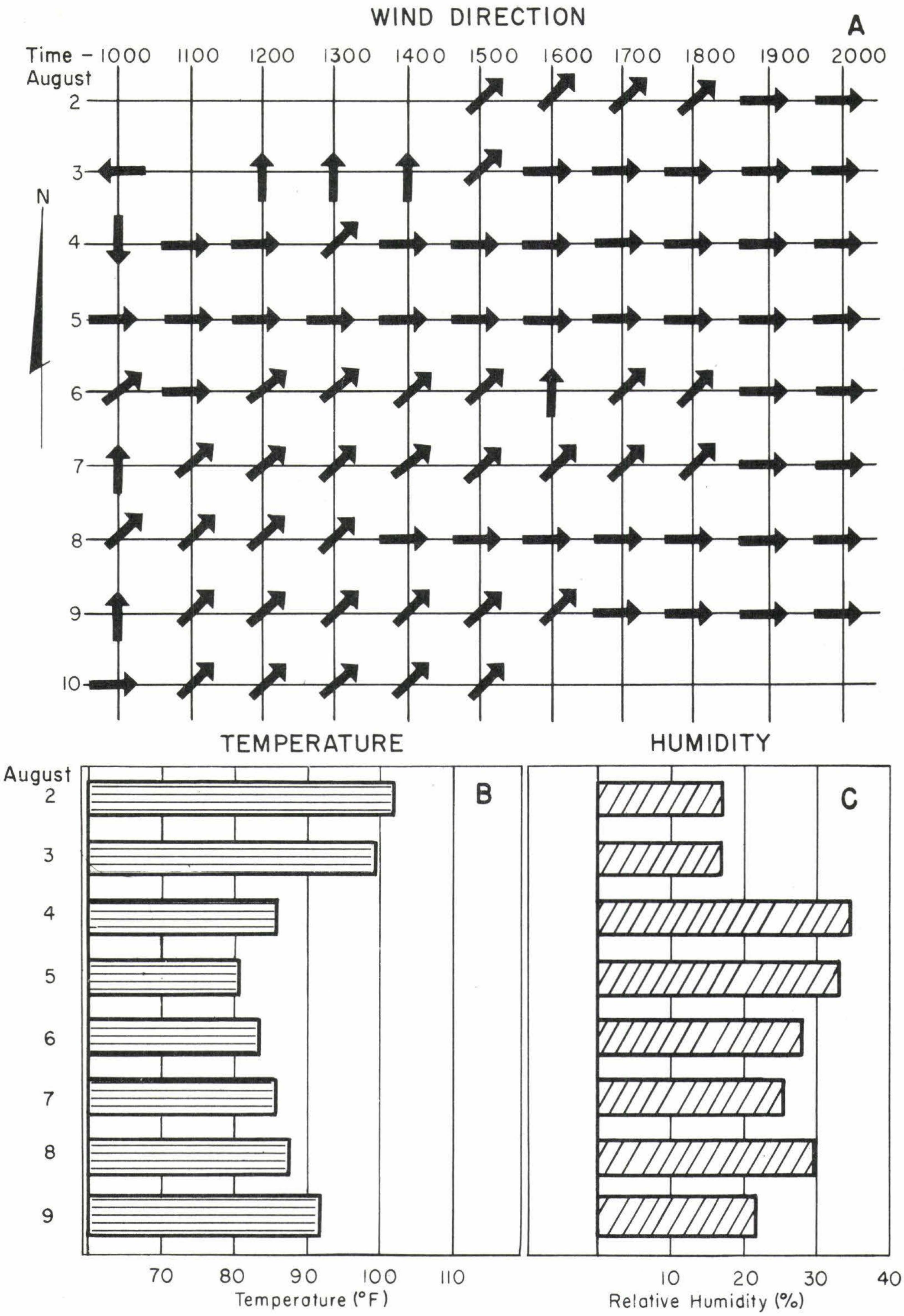


Figure 10.--Effect of synoptic weather on wind direction, temperature, and humidity at Station 6.

## Effect of Synoptic Weather on Local Fireclimate Patterns

The movement of cooler air into central California during the first part of the survey had a marked effect on the wind patterns in the survey area. At Station 6, for example, the survey indicated that the "normal" daytime wind direction was from the southwest, switching to west early in the evening (fig. 10a). As early as August 3, however, this pattern was disrupted by southerly winds in the early afternoon and a change to west winds in the late afternoon. West winds predominated on August 4 and 5--the time of strongest penetration of marine air into the area. On August 6 the usual pattern again appeared.

The effect of the invasion of marine air on maximum temperature and minimum humidity was also very apparent. The maximum temperature dropped from 100 on August 3 (fig. 10b) to 81 on August 5. Beginning with August 6 the maximum temperatures showed an upward trend which continued through the rest of the survey period.

In general the relative humidity followed the inverse of the temperature trend, as could be expected. On August 8, however, the minimum humidity was slightly higher despite higher temperature than either August 7 or August 9 (fig. 10c). Wind direction was predominately west during the afternoon of August 8 also. The westerly wind direction and higher humidity suggested some additional penetration of marine air.

The influence of the marine air was also clearly shown at Station 3. On August 4 and 5 the wind was from the northwest (fig. 11). As at Station 6, the more normal pattern returned on August 6. Some disruption of this pattern on August 8 occurred at Station 3 also.

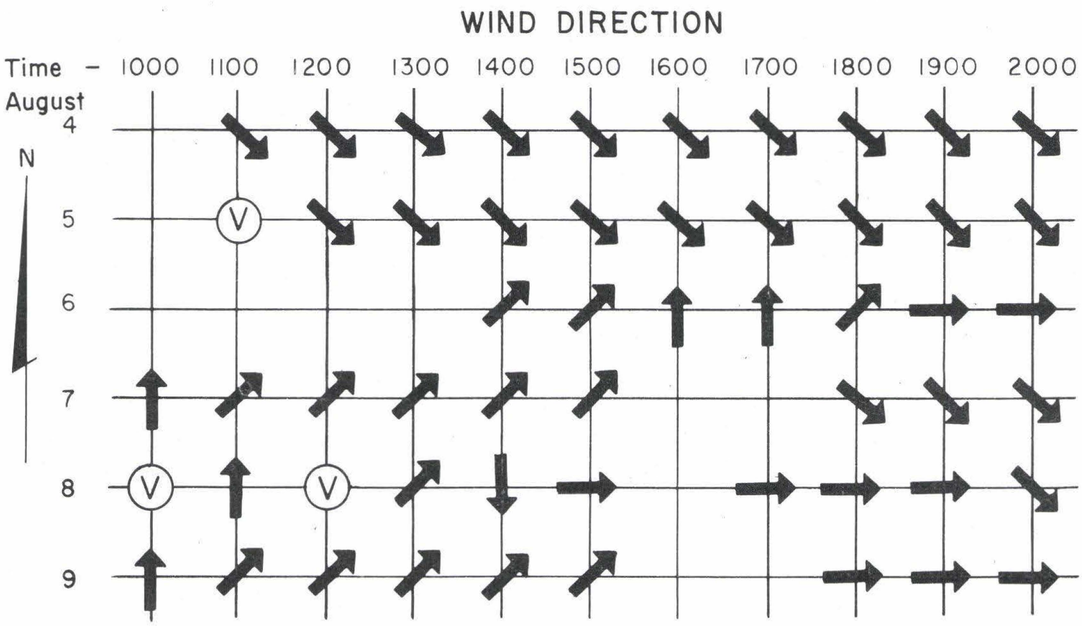


Figure 11.--Effect of synoptic weather on wind direction at Station 2.

Fire-Weather Forecast

Utilizing detailed observations from the burn area and general weather and forecast data from the U. S. Weather Bureau, we were able to prepare the following detailed fire-weather forecast for the day of the burn.

Fire-Weather Forecast For Red Hill Prescribed Burn, Saturday, August 10, 1957

"In general there will be little change from the weather observed today, (August 9). Lowest temperature Saturday morning will be 56° and highest relative humidity 85 percent occurring about 0600P. During the forenoon temperatures will be rising rapidly and humidities falling rapidly. By 0800P temperature will be about 75 degrees and humidity about 40 percent. By 1100P values will be about 88° and 30 percent. Maximum temperature Saturday afternoon 90-92, minimum humidity 20-25 percent. These will occur around 1500P.

"The wind pattern Saturday will be similar to that observed today (August 9). General flow aloft over the area will be southwesterly 6 to 12 m.p.h. This flow will have little effect on the burn area during the nighttime and early morning hours except exposed ridges. As a result, local effects will be dominant during that time and light down-slope and down-canyon winds will prevail especially on east-facing slopes and canyons opening to the east. Speeds will be 1 to 4 m.p.h.

"As the sun begins to warm the east-facing slopes, and canyons opening in that direction, light up-slope and up-canyon winds will set in. The change will take place between 0600 and 0700P. Up-canyon winds of 2 to 4 m.p.h. will continue until around 1000P. By then west to southwest winds west of the main ridge will have become stronger and will flow through the gaps, and winds will become down-canyon again at least in the upper portion of the canyons. These winds will be variable in speed mostly 4 to 8 m.p.h. and at times will reach the reservoir. In the lowest portions of the canyons and down near the reservoir winds will be extremely variable in direction and speed. At times the westerly down canyon winds will reach the water, at other times southeasterly winds moving up the reservoir will cover that area. Speeds will vary from calm to 5 to 7 m.p.h.

"On the west-facing slope winds will be northwesterly 1 to 4 m.p.h. at night, gradually changing to west and southwest during the early forenoon (0600-0900) and increasing slightly in speed. Speeds at 1000 on will be 5 to 10 m.p.h., quite variable, with gusts occasionally 16 to 18 m.p.h.

"During the warm part of the day the layer of air near the surface will be unstable, but there is no indication of a deep layer of unstable air that could result in erratic fire behavior.

"Skies will remain clear."

Actual weather conditions followed very closely those predicted for the area. Forecast and actual temperatures and humidities at Station 6 were:

| | Forecast | Actual |
|---|---|---|
| Temperature: | | |
| Minimum | 56 | 58 |
| Maximum | 90-92 | 91 |
| 0800 Hours | 75 | 80 |
| 1100 Hours | 88 | 88 |
| | Forecast | Actual |
| Humidity: | | |
| Maximum | 85 | 66 |
| Minimum | 20-25 | 23 |
| 0800 Hours | 40 | 39 |
| 1100 Hours | 30 | 25 |

Actual wind speed and direction and time of wind shifts also followed very closely those predicted.

## Fire Behavior

The firing plan called for burning to begin about 0800 hours in the southeast corner of the area, where possible trouble in holding the fire was foreseen because of dense fuels and difficult terrain. After this area was under control the fire was to be carried along the south and west side of the burn area to the head of Survey Canyon. At the same time firing was to start in Survey Canyon near Station 4A and carried down to the reservoir. It was planned to have the firing in the lower part of Survey Canyon completed well before 1000 hours so as to take advantage of up-canyon winds. The rest of Survey Canyon was then to be fired.

Burning out the southeast corner of the area took longer than expected so that firing was not started around Station 4A until nearly 1020 hours--after down-canyon winds had already set in. Firing of the rest of the burn perimeter was similarly delayed.

Actual fire behavior was amazingly close to that indicated likely by the wind pattern maps. In Survey Canyon numerous spot fires appeared across the fireline around Station 4, coalesced into a front and ran to the top of North Ridge. This was a portion of the perimeter where the survey revealed persistent southwest winds blowing across the fireline (figs. 5,6,7,8).

Figure 12.--Firewhirl near Station 3.

The fire became well established along South Ridge to the south of Stations 5B and 5C about 1200 hours. It moved along the ridge in an easterly direction at moderate speed and with a hot front. When the fire reached a point southwest of Station 2B (about 1240 hours), a large counterclockwise firewhirl developed. The whirl then moved with the fire easterly along the ridge, passing over and wrecking Station 3 (fig. 12). The whirl dissipated before reaching Station 1.

The tendency for firewhirls to form most readily on the lee side of ridges has already been well documented.[1/] In this case the whirl developed in the general area where the wind survey had shown the probable existence of eddy circulations (fig. 5,6,7,8). Although eddy circulation probably is not a necessary prerequisite for the genesis of a firewhirl, it can be expected to make the development of the whirl more likely. Eddy circulations, then, can be a warning of probable firewhirl development, particularly on lee sides of ridges.

Another incident suggests a promising line of study. About 1145 the fire reached Station 1 from the south and southwest. Because of the light fuels in this area, the fire burned with low intensity and little convective activity. About 1150, however, the fire spotted to the east side of the reservoir directly across from Station 1. The spot was estimated to be 1,500 to 2,000 feet from the nearest fire. During the burn we noticed that the smoke seldom got down to the water level but crossed the reservoir above the water and touched the ground about 1/4 the way up the opposite slope--about where the spot fire occurred.

The behavior of the smoke suggests a layer of relatively cool air over the reservoir. Air warmed by contact with the ground and by the fire could be expected to flow over this layer of cool air above the water and thus permit spotting to a greater distance than normal for existing conditions of fire and wind. This study was not extensive enough to substantiate this possible air flow pattern. The prevalence of situations where such a differential temperature could exist, such as deep canyons with or without water, reservoirs, and lakes, makes investigation of this potential cause of long-distance spotting of major importance.

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1/ Graham, Howard E., Fire Whirlwinds. American Meteorological Society Bulletin, 36(3): 99-103 March 1955

## CONCLUSIONS

Information derived from this survey, while not conclusive in itself, has contributed much to our understanding of local fireclimate patterns and has indicated the direction more exhaustive research should take. Because the survey was conducted during the time of a change in synoptic weather we were able to relate this change to its effect on the local weather patterns, and to obtain some concept of the probable importance of such change on fire behavior.

From the knowledge gained of the local fireclimate pattern in the burn area, it appeared that in this case the fireclimate had far more effect on the fire behavior than the fire did on the fireclimate pattern. The fire behavior followed very closely that which could be expected from the wind pattern for the area, even to the extent of a firewhirl developing in an area where vertical eddy circulation was indicated by the survey.

Of particular interest is the possibility, suggested by the survey, that cool air over bodies of water or in canyons might contribute to long-distance spotting. More study of this effect is needed before any conclusions as to its actual importance can be made.